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FORECASTING THE FORMATION AND MOVEMENT OF THE CEDAR KEYS HURRICANE, SEPTEMBER 1–7, 1950[1]

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ABSTRACT

The Cedar Keys hurricane of September 1–7, 1950, formed south of Cuba and crossed the west coast of Florida near Cedar Keys. Thus its entire life was spent in an area where considerable upper air data were available, and during September 3–6 it was tracked almost constantly by either airborne or land-based radar. Its path was extremely erratic. Analyses of surface and upper air data are used to explain the formation and various changes in rate and direction of movement of the storm, including two loops in its path. The concept of steering, as used in the Weather Bureau's Hurricane Warning Center at Miami, and other forecasting tools are discussed.

CONTENTS

INTRODUCTION

The Cedar Keys hurricane of September 1–7, 1950, was notable for its erratic course (fig. 1 A). It was first discovered by aerial reconnaissance south of the Isle of Pines during the afternoon of September 1. For 36 hours it moved northward at 3 to 4 m. p. h., then it suddenly started moving 22 to 23 m. p. h. in a direction between north and north-northeast. This rate continued for about 10 hours during which the course gradually changed to one between north and north-northwest. For the next 14 hours it moved toward the north-northwest at 12 to 13 m. p. h. Then just as suddenly as it had started moving, it became nearly stationary again for 14 hours while it moved slowly in a counterclockwise loop. After completing the loop, it moved at 7 m. p. h. toward the northeast. It continued this course for 12 hours and again became quasi-stationary while making another counter-clockwise loop. After completing this loop, it moved toward the south or south-southeast at 4 m. p. h. for 12 hours. Finally, it gradually curved toward the east and then the north to a track that was more conventional for hurricanes. Throughout its history, the storm continuously threatened Florida, and from 0700 EST, September 3 until it lost its hurricane force early September 6, hurricane winds were either affecting the Florida coast or were within about 60 miles of the coast.

Because of the storm's nearness to land, sufficient data were collected to plot its path in detail. Furthermore, the hurricane was within the network of the United States and Cuban upper air stations from the time it developed until it dissipated. Thus, considerable data are available for the study of this storm that is especially interesting because its erratic movements presented great problems to the forecasters.

This research was started in the hope that solutions to certain definite problems could be found: (1) Why did the hurricane form? (2) Why did the hurricane accelerate

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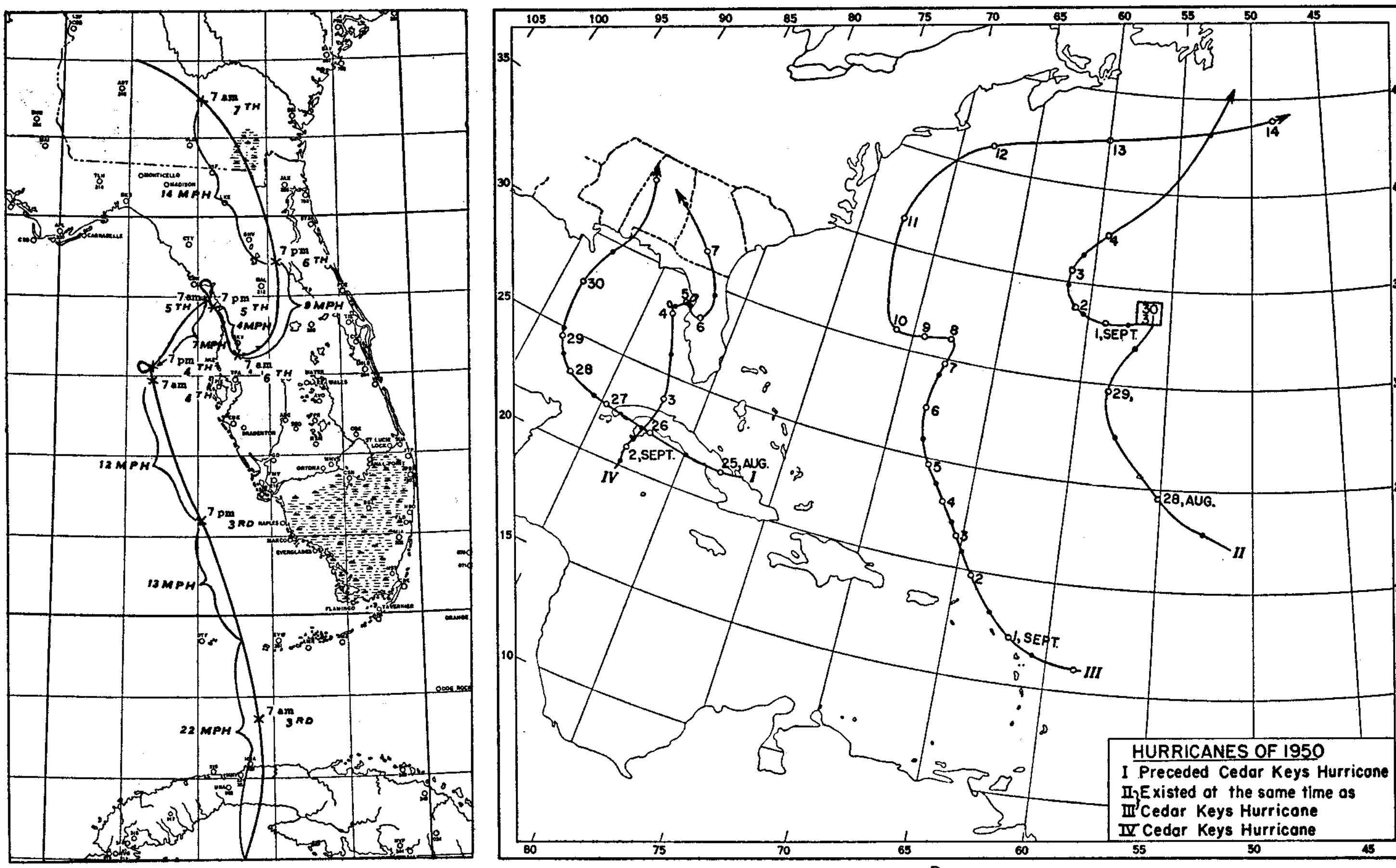

A B

FIGURE 1.—A. Map section showing track of Cedar Keys hurricane in detail. B. Tracks of hurricanes which existed prior to and during the time of the Cedar Keys hurricane (IV). Open circles mark position of center at 0730 EST; solid circles, 1930 EST position.

so rapidly on the night of September 2–3? (3) Why did the hurricane move so slowly and make two loops on September 4–5? (4) How could the movement toward the south or south-southeast on September 5–6 have been forecasted? (5) What was the best available method for forecasting movements of this hurricane?

In studying the movement and formation of the hurricane, the following maps and charts were used: Sea level weather maps; constant pressure maps at 850 mb., 700 mb., 500 mb., and 300 mb.; pibal charts at selected levels from 2,000 feet to as high as the winds were reported; pseudo-adiabatic charts of the upper air soundings at Tampa, Miami, and Havana; time cross section for Tampa; and mean virtual temperature charts for the layer between 700 mb. and 500 mb. Most of the final conclusions were based on the constant pressure charts. Tracks on the 300-mb. charts give 12-hour positions of the height centers at that level. Tropical storm symbols on the constant pressure maps give the concurrent surface location of the storm's center.

FORMATION

On August 26 another hurricane had passed near the Isle of Pines moving from the east (fig. 1B). It crossed the western end of Cuba, intensified in the Gulf of Mexico, turned northward, and crossed the Gulf coast just east of Mobile. A trough of low pressure remained over the Western Caribbean after this earlier storm had passed into the Gulf, and the Cedar Keys hurricane formed in this trough. It was first located by aerial reconnaissance on the afternoon of September 1. However, rain had been very heavy over all of western Cuba and the waters between Swan Island and Cuba for 2 days previously, and a closed Low had developed in the levels near the surface.

On the night of August 31–September 1, the widespread heavy rain seemed to become concentrated in the area south of the Isles of Pines. By this time, the sea level pressure had fallen to 1,005 mb. (fig. 2) and possibly lower. Thus conditions were ripe for tropical storm development according to Riehl [1] if some mechanism were in the higher levels above the area of surface low pressure to remove some more air and cause deepening of the disturbance. Although upper air data are too sparse to make a quantitative analysis of divergence of the wind field at higher levels, data available indicate that horizontal divergence took place above the incipient center.

The equation for gradient winds on the rotating earth is

$$\frac{1}{\rho}\frac{dp}{dn}=fv\pm\frac{v^2}{r}$$

where ρ is density; p is pressure; n is distance measured normal to the isobars; f, the Coriolis parameter; v, the

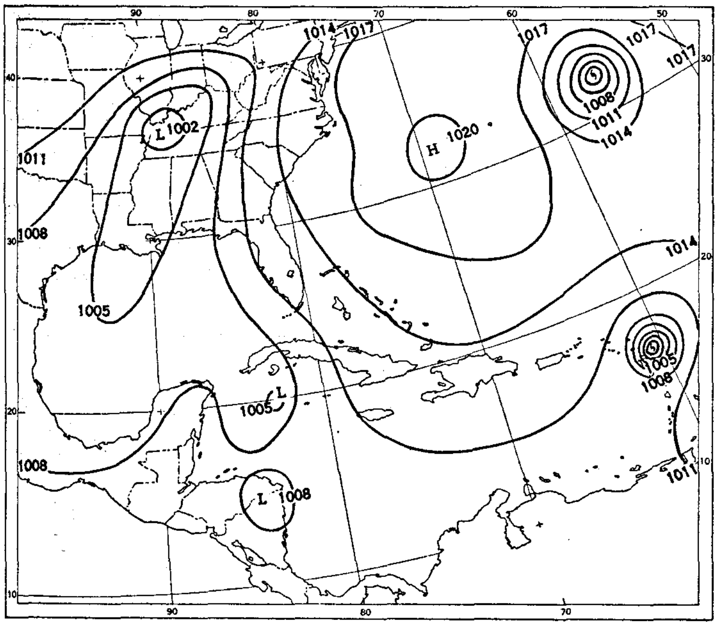

FIGURE 2.—Chart showing sea level isobars for 1930 EST, August 31, 1950.

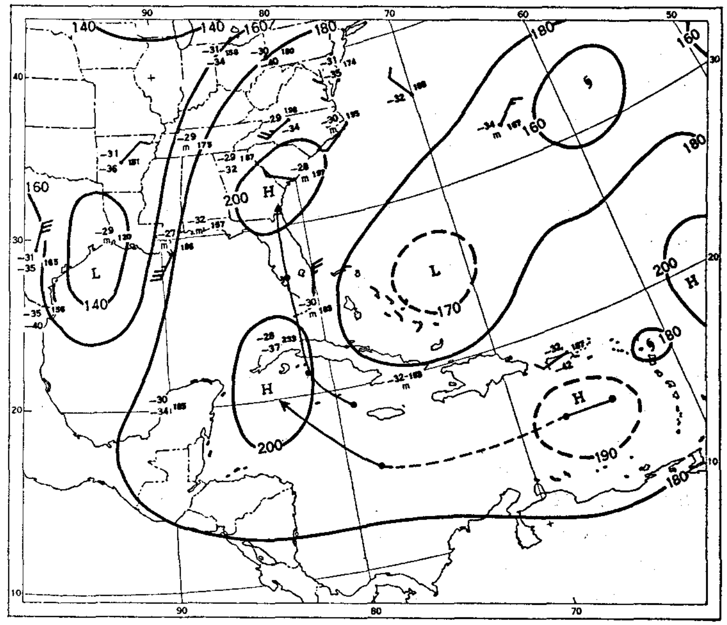

FIGURE 3.—300-mb. chart for 2200 EST, August 31, 1950. Tracks show 12-hour movement of Highs.

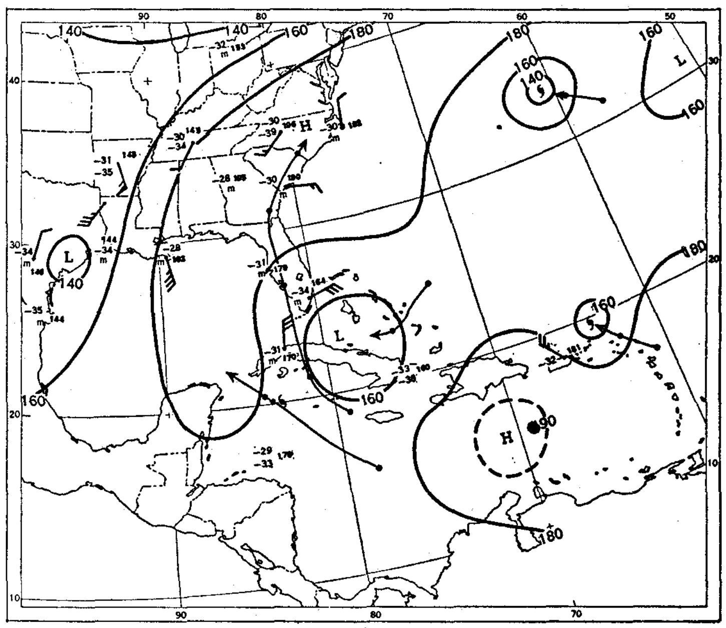

FIGURE 4.—300-mb. chart for 2200 EST, September 1, 1950. Tracks show 12-hour movement of Highs and Lows.

wind velocity; and r, the radius of curvature of the particle path. The positive sign is used for cyclonic paths and the negative sign for anticyclonic paths. Thus in steady flow the force due to the pressure gradient is balanced by the deflecting forces and the wind flows parallel to the isobars or contours. However, if the pressure gradient is increased, the terms on the right no longer balance it; for due to the conservation of momentum, air particles may not assume immediately the velocity called for by a changed pressure gradient. Since the deflective forces vary with the velocity, they will not balance the pressure gradient force until the wind is steady again.

Tracks on maps of 2200 EST August 31 (fig. 3), and 2200 EST September 1 (fig. 4) show that at 300 mb. a high pressure system moved over the developing storm on the night of August 31, and stayed in that vicinity for about 24 hours before resuming its northwestward course. At the same time cyclogenesis occurred in the trough to the east. Stagnation of the High and deepening of the trough resulted in increased pressure gradient and accelerating winds at 300 mb. above and east of the storm, e. g., the winds at Miami and Havana accelerated considerably at 300 mb. and higher levels. So long as the winds were sub-gradient, there would be horizontal divergence over the developing center, for the pressure gradient force would be larger than the deflecting forces in our equation. Since the pressure force is directed toward low pressure (to the left when looking downstream), this would cause a net movement of air from high toward low pressure. That is, it would cause air at 300-mb. and higher levels to move from the High above the developing storm center toward the low pressure trough to the east.

Once the storm had started there was plenty of energy available to keep it going and to cause intensification. Palmén [2] has explained that once a hurricane is formed, its solenoidal field is such that it will maintain itself as long as the air feeding into it near the surface is warm and moist and there is not too much surface friction. The air south of Cuba on September 1 met all specifications.

OBSERVED MOVEMENT

Once the storm had formed, the next problem was to predict its course and rate of movement. The difficulty of doing this has already been suggested by the erratic course shown in figure 1A, and it is of interest to evaluate the observational evidence for this path before discussing the forecasting problem in detail.

The hurricane path was plotted from a combination of reports from aerial reconnaissance and land stations. As stated previously, the center was first located by aerial reconnaissance. While the storm was south of Cuba, two fixes a day on the center were secured by reconnaissance. The storm passed over the Isle of Pines and just east of Havana where the wind dropped off to 10 or 15 m. p. h. (fig. 1A). It passed between the weather stations at Key West and Dry Tortugas. Reconnaissance crews flew into the center several times September 3–4, and either airborne or land-based radar tracked it almost constantly from the time it left Cuba early September 3 until it lost its hurricane force in the area just north of Tampa early September 6. Reports from points along the Florida coast including the lighthouses furnished approximate positions of the storm and confirmation of the more precise fixes furnished by radar. Also, some ships in the eastern Gulf at the time gave valuable reports.

The loop in the path when the center was west of Anclote Key (fig. 1A) was very small in diameter. However, five successive radar fixes secured September 4, outline the loop. Also at that time, the hurricane had almost no forward movement. Thus we may conclude that external forces moving the storm were very weak. Under such conditions, movement of the storm would be due to the internal forces in the storm itself. In this case it would tend to move in a circle counterclockwise if the storm was perfectly symmetrical [3]. The loop in the path just east of Cedar Keys is partially based on the radar observations of the center and partially on observations at Cedar Keys. The wind at Cedar Keys gradually backed from east-northeast to north as the eye approached on September 5. The calm eye was over the station for about 2½ hours. After the lull the wind started from the east-northeast and again gradually backed to the north as the eye moved farther away. Thus the people there had the unique experience of being exposed to the same side of the hurricane twice. The observed wind shifts indicate that the center first approached the Florida coast to the east of Cedar Keys then moved westward until the western edge of the eye was over the station. When the storm started moving again, it was toward the east or southeast and thus a loop to the east of Cedar Keys was completed.

As the storm approached the coastline, it was tracked by two radar observers. One was at the University of Florida at Gainesville, the other was airborne in a Navy plane. Seven fixes furnished the Hurricane Central at Miami from the Navy plane coincided in time with fixes furnished by the University of Florida. Although it is impossible to say which of the two groups of fixes is more nearly correct, we can obtain some idea of the accuracy of the fixes by comparing them. They were obtained by two different crews, using two different radars, and working entirely independently of each other.

The situation was nearly ideal for use of radar in tracking. The hurricane was at or near the peak of its development. It had a well developed eye that varied in diameter from about 18 to 25 miles. It was near enough to land for the Navy crew to use land fixes in pinpointing the center, and it was within range of the land-based radar set at the University. Thus, if ever accurate fixes should be obtained by use of radar, it should have been at this time. Table 1 summarizes the differences in the fixes.

TABLE 1.—*Differences in location of hurricane center, September 5, 1950*

Time	Distance between two fixes	Approximate distance from Navy fix to nearest land	Approximate distance of University fix from radar set
GMT	*Miles*	*Miles*	*Miles*
0630	10	42	104
0830	10	35	88
0900	13	34	88
1000	10	30	84
1030	11	28	83
1130	5	21	80
1230	5	10	73
Average	9.1		

If we assume that either of the crews made absolutely accurate fixes, the errors made by the other group varied from 5 to 13 miles. If we assume that the true position of the hurricane was half way between the corresponding fixes, the average error was 4.6 miles. This is certainly acceptable from the standpoint of accuracy.

In earlier days, forecasters ordinarily used fixes at least 12 hours apart in calculating direction and rate of movement of hurricanes. While that may not be necessary now with the more complete data that are available, a smoothed path such as that given by the 12-hour fixes is still best in computing long-period direction and rate of movement. Short-period fluctuations in direction and rate of movement of the hurricane's center as determined from fixes by the two radars are illustrated by table 2.

From 1000 GMT to 1130 GMT the University of Florida reports indicated that the hurricane was moving at 3 m. p. h. in a direction of 40°, and the Navy radar reports indicated that the hurricane was moving at 8 m. p. h. in a direction of 80°. It is not within the scope of this report to determine the sources of error leading to these conflicting indications, but it is obvious that even though individual fixes on the center are relatively accurate, two succes-

TABLE 2.—*Direction and rate of movement of hurricane*

Time (GMT)	Movement indicated by fixes from University of Florida		Movement indicated by fixes from Navy radar plane	
	Direction (degrees)	Speed (m. p. h.)	Direction (degrees)	Speed (m. p. h.)
0630–0830	20	8	20	8
0830–1000	50	3	50	3
1000–1130	40	3	80	8
1130–1230	40	8	50	10
0630–1230	30	5	40	6
0245–1230			40	8
0245–0830			30	6

sive fixes taken too close together can give erroneous indications of movement if both happen to be off in such a manner as to make the errors additive.

Radar reports have been very helpful to forecasters during the past few years, though knowledge of maximum winds in the circulation and distribution of winds around the center is also necessary to do an acceptable job of forecasting the storm. Furthermore, in using radar reports, forecasters must keep in mind that the reported position of the storm center is only an estimated point in the radar rainfall pattern around which the spiralling bands of precipitation seem to circulate; i. e., it is the eye in the rainfall pattern. It is often difficult to pick this point. An inexperienced observer may be tempted to call the center of the innermost band of precipitation the eye, rather than to trace carefully the echoes on the scope long enough to pick the center of rotation. If this band is not symmetrical with respect to the center (and it often is not), an error is introduced. Moreover, the estimated center observed by radar is not necessarily the center of the wind field, nor the point of lowest pressure. Ordinarily, it is the same as the pressure center for all practical purposes, but in immature storms, dissipating storms, or storms that have had their lowest layers disturbed while passing over land, this center observed by radar may be vastly different from the pressure center. Ordinarily radar observers recognize such situations and so report in their remarks.

In the case under discussion, as the storm approached Cedar Keys, the eye was well defined and the center observed by radar should have corresponded very closely to the pressure center. The small differences between the two series of reports can be accounted for by human errors of observation and by mechanical errors of the two radar sets.

After the storm crossed the Florida coast, it was tracked by the radar crew at the University of Florida until it began to dissipate early September 6, north of Tampa. In addition, reports from the regular weather stations supplemented by reports from laymen over which the storm passed, enabled us to track it accurately through Florida.

FORECASTING THE MOVEMENT

METHODS OF FORECASTING

In next considering the problem of predicting the course and rate of movement of the Cedar Keys hurricane, it is well to recall that there are several methods used to predict the course of a hurricane. It is well known of course, that there is a tendency for hurricanes to recurve into any polar trough passing to the north if the trough extends far enough south. However, there may be some element controlling both the movement of the hurricane and the movement and location of the trough rather than the trough attracting the hurricane.

From the beginning forecasters have used persistence in making their forecasts. That is, they forecast what has been happening will continue to happen. From the track chart (fig. 1A) it is obvious that depending on persistence would have given very poor results because the course and rate of movement changed many times.

Simpson [4] argues that hurricanes tend to move parallel to the axis of the warm core that extends in advance of the storm. This gives good results in many instances.

Riehl and Burgner [5] have developed an objective method of forecasting the zonal component of hurricane movements using 5-day mean 700-mb. maps. Since most of the movements of the Cedar Keys hurricane were north-south rather than east-west, this method was not used in the present study.

Fujiwhara [6] observed that two co-existing typhoons often rotate around each other and more recently, Haurwitz [7] presented a theory on the motion of tropical cyclone pairs. These theories are particularly interesting for this study because another hurricane was located in the Atlantic east of the Bahamas at the same time the Cedar Keys storm was tracing its erratic course.

In the Weather Bureau's Hurricane Warning Center at Miami, a concept of steering has been developed, mostly by Mr. Grady Norton, and through the years it has been considered the most dependable of any of the methods when sufficient data were available. Bowie [8] was one of the first forecasters to argue that movements of hurricanes were controlled by currents high in the atmosphere, but even in the earliest of the hurricane literature, one can find references to hurricanes following currents at the cirrus level.

The concept of steering developed by Mr. Norton differs somewhat from that used by many forecasters. The difference lies largely in the selection of the steering level. Mr. Norton does not use the same level all the time. In fact, he may use several different levels for the same storm, varying the level with the stage of development of the hurricane. In principle, he argues that a hurricane will move with the current that flows across the top of the warm core of the hurricane or rather that it will cut across this current at an angle of 10° to 20° toward high pressure. In practice, this method requires that one study the pibal charts and select the lowest level where winds over the surface position of the hurricane are not in the circulation of the hurricane, i. e., the winds over the hurricane seem to fit into a smooth pattern with the winds upstream and downstream from the hurricane. For example, in figure 5 which gives upper winds from an earlier storm, winds at Hatteras are obviously affected by the circulation of the hurricane up to at least 30,000 feet. From data at Hatteras, Charleston, and other nearby stations, one can deduce that the winds over the storm are still in the hurricane's circulation as high as 35,000 feet. However, at 40,000 feet the flow appears to be relatively smooth over the top of the hurricane, and this should be selected as the steering level. The hurricane symbol gives the position of the hurricane at the time of the pibal observations,

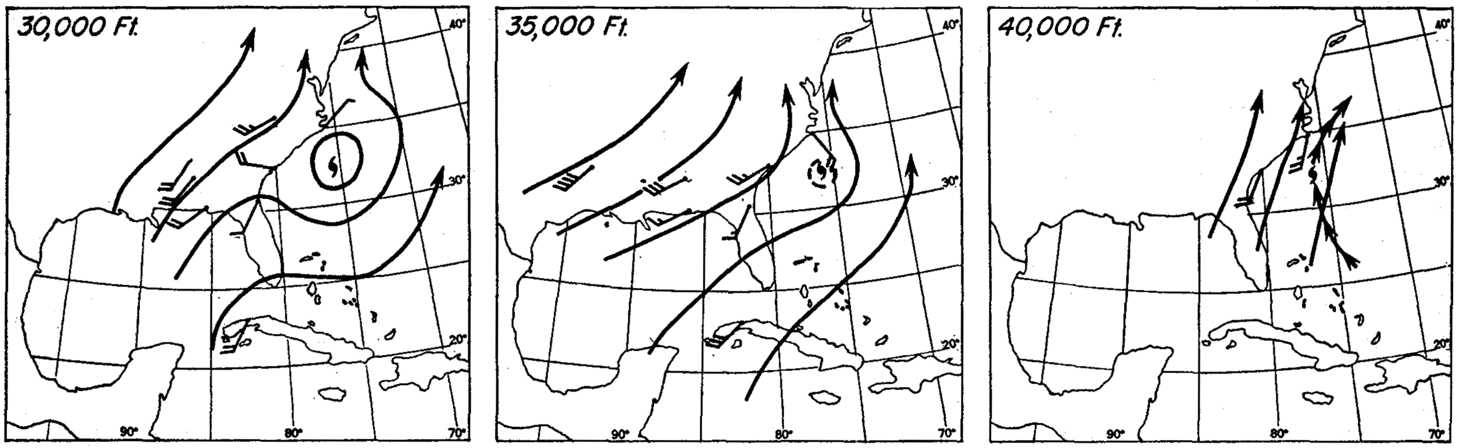

Figure 5.—Charts showing air flow over the southeast United States at 1600 EST, August 19, 1950, at (a) 30,000 feet, (b) 35,000 feet, and (c) 40,000 feet.

and the arrow gives the path of the hurricane before and after the pibals were taken. Using the concept of steering, forecasters were able to successfully predict that the center would pass to the east of Cape Hatteras. Previously, this concept of steering has given consistently good results when sufficient data were available for using it. Mr. Norton also believes that the rate of movement is highly correlated with the speed of the steering current. Qualitatively, this idea has been used and found correct, but unfortunately, there have never been sufficient data to check it quantitatively.

For some of the mature Cape Verde storms, the steering level is as high as 55,000 to 60,000 feet. Of course, data are seldom available to that height immediately over the storm. However, when pressure systems at the steering level are all large and streamlines relatively smooth, one can often deduce what the winds are over the storm from data at stations 500 to 1,000 miles away. However, when the flow at the steering level is broken up into several small vortices, it is very risky to make any deductions from data at long distances from the center. This was true of the Cedar Keys hurricane. Even a casual study of the 300-mb. maps in this series (figs. 3, 4, 6, 8, and 9) reveals that Highs and Lows in the vicinity of the hurricane were comparatively small in diameter.

In studying this storm, all of the forecasting methods were tried which were applicable to the situation. Since the high level steering concept gave best results, it is the only one that will be discussed.

APPLICATION OF THE STEERING CONCEPT

The first problem in forecasting the movement of the Cedar Keys hurricane was to account for the change on the night of September 2–3, when it accelerated from a forward speed of 5 or 6 m. p. h. to one of 22 or 23 m. p. h. At this stage of the storm development, one would have

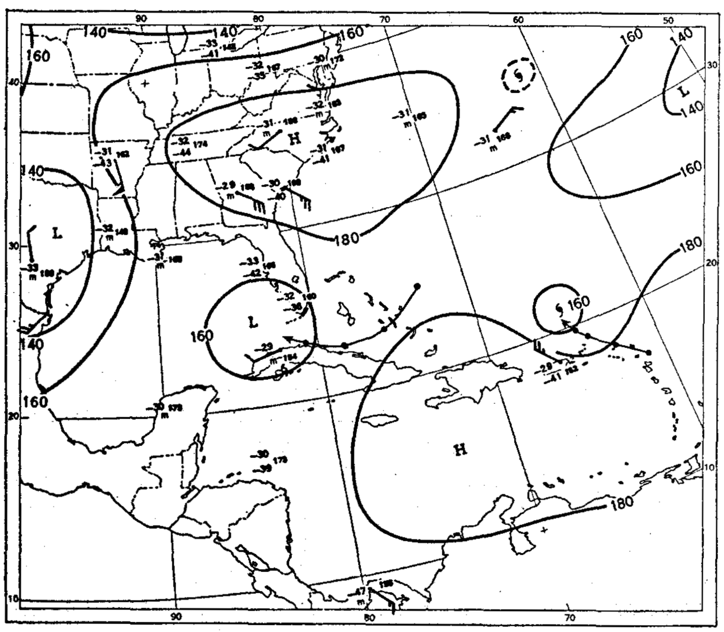

Figure 6.—300-mb. chart for 2200 EST, September 2, 1950. Tracks show 12-hour positions of Lows.

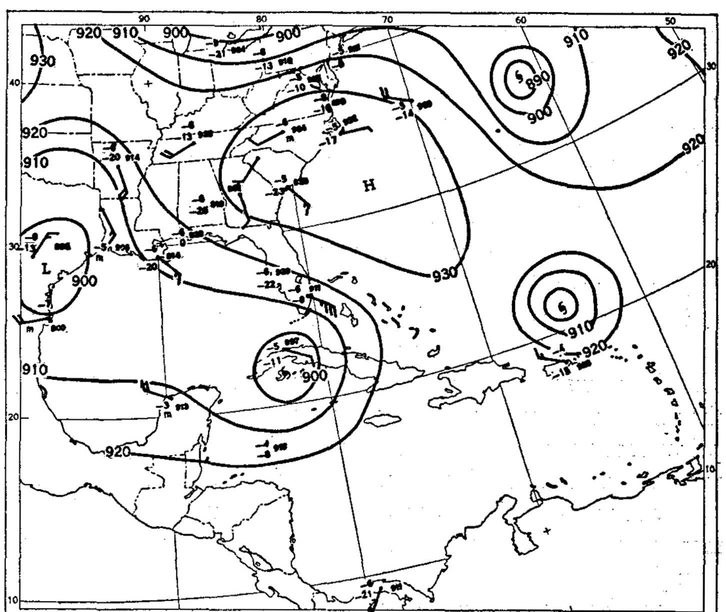

Figure 7.—500-mb. chart for 2200 EST, September 2, 1950.

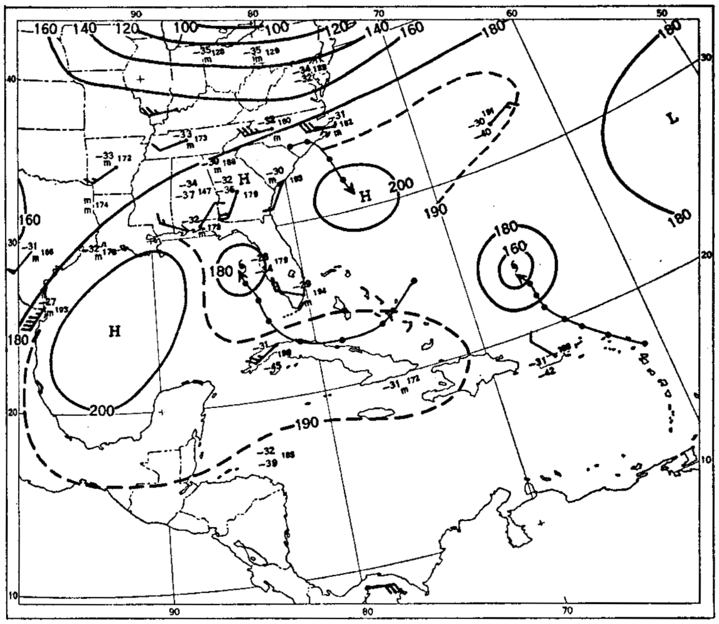

FIGURE 8.—300-mb. chart for 1000 EST, September 4, 1950. Tracks show 12-hour movement of Highs and Lows.

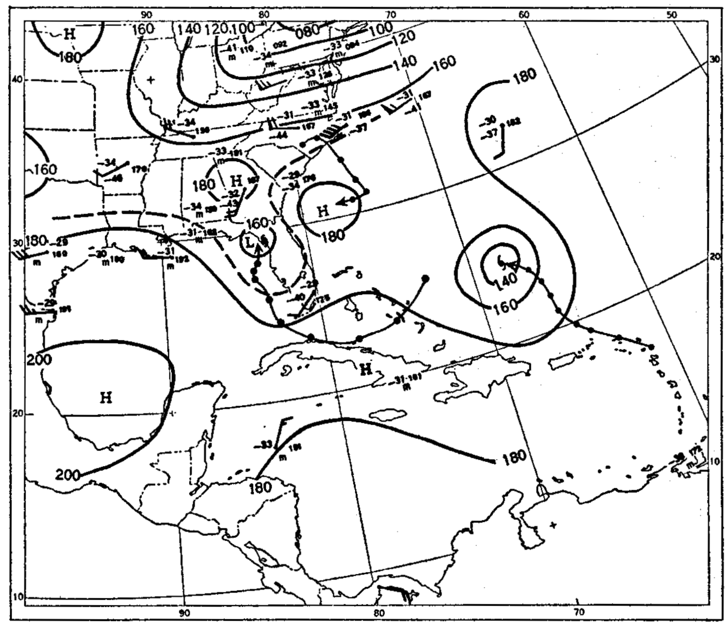

FIGURE 9.—300-mb. chart for 1000 EST, September 5, 1950. Tracks show 12-hour movement of Highs and Lows.

expected to find the steering level somewhere near 30,000 feet. The 30,000-foot winds at Havana at 2200 EST, September 2, (fig. 6) were taken at about the time of the acceleration and they were from a westerly direction and very weak—nothing there to indicate a sudden acceleration toward the north-northeast. However, at 300-mb. cyclogenesis had taken place east of Miami and by 2200 EST September 2, the resulting Low had moved to a position north-northwest of Havana. (See figs. 3, 4, and 6 and the tracks thereon.) Before 2200 EST the top of the circulation of the hurricane was apparently shortly above the 500-mb. level (fig. 7). However, at about this time the circulation of the Low at 300 mb. which had moved in from the east was nearly superimposed on the circulation of the hurricane. This 300-mb. Low was moving at about 15 m. p. h. and when it reached this position north-northwest of Havana, it recurved toward the north—following about the same path taken by the High that preceded it. (See track of High centered over North Carolina on 300-mb. map for 2200 EST, September 1, (fig. 4.).) At 2200 EST, September 2, this 300-mb. Low was centered north of the hurricane, but it was close enough to join the circulation of the hurricane. However, because of its northward position, it made the vertical axis of the hurricane tilt toward the north an abnormal amount. The acceleration was probably due to the circulation of the storm being picked up by the circulation of the 300-mb. Low which was steered by some current quite a bit higher. Unfortunately, data from high levels were not secured, and the steering level for the 300-mb. Low cannot be located. The hurricane moved at the speed of the 300-mb. Low plus an additional speed required for the lower part of the hurricane to catch up with the upper part. Thus the surface center moved at about 23 m. p. h. until it caught the 300-mb. Low. The latter had been moving about 15 m. p. h. but it slowed down some when it recurved to the north. As soon as the surface center caught the 300-mb. Low, it slowed down to 12 to 13 m. p. h.

On September 4 the hurricane became quasi-stationary so far as forward movement was concerned and traced the first of the loops in its track. At this time, the hurricane and the 300-mb. Low were apparently just one Low, and the steering level was apparently somewhat above the 300-mb. level. Again winds at the higher levels were not available in sufficient quantity to pick a steering current. However, from the height distribution on the 300-mb. chart, one can deduce that the steering winds were very light, for gradients near the storm were weak, and the hurricane was located about midway between the High in the Gulf of Mexico and the High in the Atlantic east of Jacksonville (fig. 8). There is no obvious reason for thinking that either of these Highs would predominate over the other at the levels shortly above the 300-mb. surface. Thus one could not be sure from the steering that the storm would stay stationary, but there is no reason for expecting much movement.

During the night of September 4, the hurricane moved slowly toward the northeast and reached the Cedar Keys area about 0700 EST, September 5. The next question is, how would the storm move when it reached the Florida coast? Sufficient winds still were not available at higher levels to accurately determine the steering level. From the flatness of the gradient near the storm at the 300-mb. level at 1000 EST, September 5 (fig. 9), it could be concluded that the steering level was not far above it, and that any movement should be rather slow.

Winds were available at Miami for higher levels. Therefore, let us study the contours on the 300-mb. map and try to deduce what winds should appear at Miami at higher levels if the north-northwest current which was

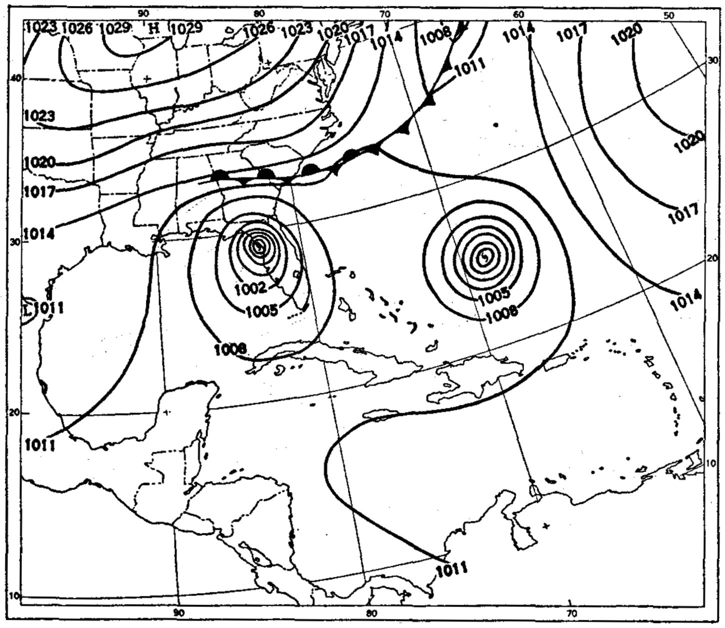

FIGURE 10.—Chart showing sea level isobars and fronts, 1330 EST. September 5, 1950.

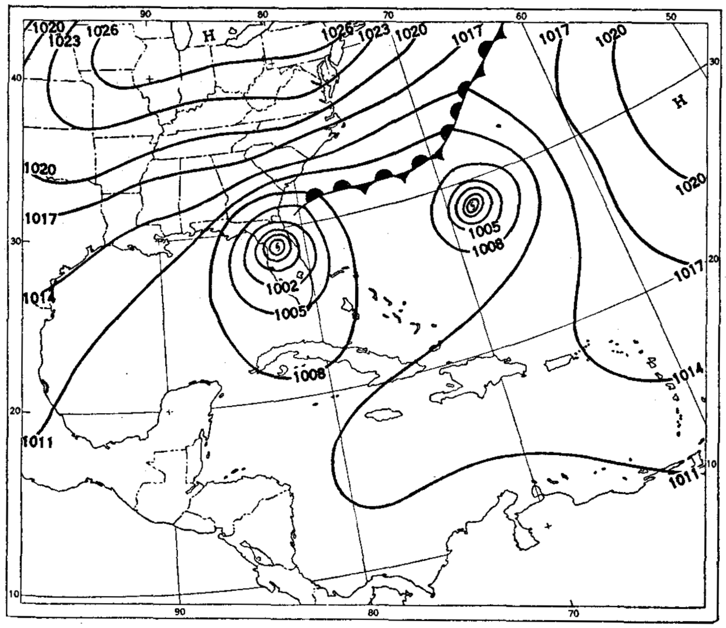

FIGURE 11.—Chart showing sea level isobars and fronts, 1330 EST. September 6, 1950.

west of the hurricane at the 300-mb. level were to appear farther east at the higher levels.

Let us assume for the sake of argument, that the entire contour pattern in the vicinity of Florida shifted farther east with height (fig. 9). Then, depending on how far east it shifted, the winds at Miami would be west, northwest, north, or possibly northeast if there were just a slight change in the shape of contours. Actually, at 35,000 feet, Miami had north winds of about 5 knots; and at 40,000 feet, had north winds of about 20 knots. This partially confirms that the steering current over the storm was from the northwest or north. Six hours later at 1600 EST while the hurricane was still moving toward the south-southeast, Valparaiso, Fla., which was west-northwest of the hurricane, reported north-northeast winds of about 20 knots. Thus all data available tend to confirm that at higher levels the flow over the hurricane was from a direction between northwest and northeast. Therefore, we can decide that the hurricane was still being steered by winds flowing over the top of the warm core. However, for this particular storm, with so many small vortices in the vicinity and with the usual scarcity of data at the higher levels, it was particularly difficult to locate the steering level and to ascertain the direction of the steering current.

At the time the hurricane became quasi-stationary near Cedar Keys, there was a large sea level high pressure system centered over Lake Michigan and its circulation extended far enough south to make contact with the outer circulation of the hurricane (fig. 10). It would have been simpler to have said that the High to the north blocked the advance of the hurricane. However, the circulation of the High never seemed to come in close contact with the stronger portion of the circulation around the hurricane. Furthermore, the High seemed to be more favorable to blocking the forward movement of the hurricane during the next day (fig. 11) when the storm was actually moving toward it than it did during the period when the storm was first quasi-stationary near Cedar Keys and then moved away from the High toward Tampa.

CONCLUSION

We have accounted for the development of the hurricane and have shown that high level steering could account for the various accelerations and changes in direction at all times when sufficient data were available. The acceleration on the night of September 2–3 could be accounted for by the movement of the warm core Low at 300 mb. and the effort of nature to return the inclination of the hurricane's axis to the vertical.

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REFERENCES

1. Herbert Riehl, "A Model of Hurricane Formation," *Journal of Applied Physics*, vol. 21, No. 9, September 1950, pp. 917–925.
2. E. Palmén, "On the Formation and Structure of Tropical Hurricanes," *Geophysica*, Finland, No. 3, 1948, pp. 26–38.
3. Tu Cheng Yeh, "The Motion of Tropical Storms Under the Influence of a Superimposed Southerly Current," *Journal of Meterology*, vol. 7, No. 2, April 1950, pp. 108–113.

4. Robert H. Simpson, "On the Movement of Tropical Cyclones," *Transactions of the American Geophysical Union*, vol. 27, No. V, October 1946, pp. 641–655.
5. Herbert Riehl and Newton M. Burgner, "Further Studies of the Movement and Formation of Hurricanes and Their Forecasting," *Bulletin of the American Meteorological Society*, vol. 31, No. 7, September 1950, pp. 244–253.
6. S. Fujiwhara, "On the Behavior of Lines of Discontinuity, Cyclones and Typhoons, in the Vicinity of Japan," *Geophysical Magazine*, Japan, Central Meteorological Observatory, vol. 2, No. 2, March 1929, pp. 120–131.
7. B. Haurwitz, "The Motion of Tropical Cyclone Pairs," *Transactions of the American Geophysical Union*, vol. 27, No. V, October 1946, p. 658.
8. Edward H. Bowie, "The Formation and Movement of West Indian Hurricanes," *Bulletin of the American Meteorological Society*, vol. 3, No. 6, June 1922, pp. 95–96. (Also *Monthly Weather Review*, vol. 50, No. 4, April 1922, pp. 173–179.)